# MODIFIED PRINTED DIPOLE ANTENNAS FOR WIRELESS MULTI-BAND COMMUNICATION SYSTEMS

## BACKGROUND AND SUMMARY OF THE DISCLOSURE

The present disclosure relates to an antenna for wireless communication devices and systems and, more specifically, to printed dipole antennas for communication for wireless multi-band communication systems.

Wireless communication devices and systems are generally hand held or are part of portable laptop computers. Thus, the antenna must be of very small dimensions in order to fit the appropriate device. The system is used for general communication, as well as for wireless local area network (WLAN) systems. Dipole antennas have been used in these systems because they are small and can be tuned to the appropriate frequency. The shape of the printed dipole is generally a narrow, rectangular strip with a width less than 0.05 $\lambda 0$ and a total length less than 0.5 $\lambda 0$. The theoretical gain of the isotrope dipole is generally 2.5 dB and for a double dipole is less than or equal to 3 dB. One popular printed dipole antenna is the planar inverted-F antenna (PIFA).

The present disclosure is a dipole antenna for a wireless communication device. It includes a first conductive element superimposed on a portion of and separated from a second conductive element by a first dielectric layer. A first conductive via connects the first and second conductive elements through the first dielectric layer. The second conductive element is generally U-shaped. The second conductive element includes a plurality of spaced conductive strips extending transverse from adjacent ends of the legs of the U-shape. Each strip is dimensioned for a different center frequency $\lambda 0$. The first conductive element may be L-shaped and one of the legs of the L-shape being superimposed on one of the legs of the U-shape. The first conductive via connects the other leg of the L-shape to the other leg of the U-shape.

The first and second conductive elements are each planar. The strips have a width of less than 0.05 $\lambda 0$ and a length of less than 0.5 $\lambda 0$.

The antenna may be omni-directional or uni-dimensional. If it is uni-dimensional, it includes a ground plane conductor superimposed and separated from the second conductive element by a second dielectric layer. A third conductive element is superimposed and separated from the strips of the second conductive element by the first dielectric layer. A second conductive via connects the third conductive element to the ground conductor through the dielectric layers. The first and third conductive elements may be co-planar. The third conductive element includes a plurality of fingers superimposed on a portion of lateral edges of each of the strips.

These and other aspects of the present disclosure will become apparent from the following detailed description of the disclosure, when considered in conjunction with accompanying drawings.

## BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a perspective, diagrammatic view of an omni-directional, quad-band dipole antenna incorporating the principles of the present invention.

FIG. **2**A is a plane view of the dipole conductive layers of FIG. **1**.

FIG. **2**B is a six-band modification of the dipole conductive layer of FIG. **2**A.

FIG. **3** is a plane view of the antenna of FIG. **1**.

FIG. **4** is a directional diagram of the antenna of FIG. **1**.

FIG. **5** is a graph of the directional gain of two of the tuned frequencies.

FIG. **6** is a graph of the frequency versus voltage standing wave ratio (VSWR) and the gain of S**11**.

FIG. **7**A is a graph showing the effects of changing the feed point or via on the characteristics of the dipole antenna of FIG. **1**, as illustrated in FIG. **7**B.

FIG. **8** is a graph showing the effects of changing the width of the slot S of the dipole of FIG. **1**.

FIG. **9** is a graph showing the effects for a 2-, 3- and 4-strip dipole of FIG. **1**.

FIG. **10**A is a graph showing the effects of changing the width of the dipole of FIG. **1**, as illustrated in FIG. **10**B.

FIG. **11** is a perspective, diagrammatic view of a directional dipole antenna incorporating the principles of the present invention.

FIG. **12** is a plane top view of the antenna of FIG. **11**.

FIG. **13** is a bottom view of the antenna of FIG. **11**.

FIG. **14** is a graph of the directional gain of the antenna of FIG. **11** for five frequencies.

FIG. **15** is a graph of frequency versus VSWR and S**11** of the antenna of FIG. **11**.

FIG. **16**A is a graph showing the effects of changing the feed point or via **40** for the feed positions illustrated in FIG. **16**B for the dipole antenna of FIG. **11**.

FIG. **17** is a graph showing the effects of changing the width of slot S for the dipole antenna of FIG. **11**.

FIG. **18**A is a graph showing the effects of changing the width of the dipole, as illustrated in FIG. **18**B, of the antenna of FIG. **11**.

FIG. **19**A is a graph of the second frequency showing the effect of changing the length of the directive dipole, as illustrated in FIG. **19**B, of the dipole antenna of FIG. **11**.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Although the present antenna of a system will be described with respect to WLAN dual frequency bands of, e.g., approximately 2.4 GHz and 5.2 GHz, the present antenna can be designed for operation in any of the frequency bands for portable, wireless communication devices. These could include GPS (1575 MHz), cellular telephones (824–970 MHz and 860–890 MHz), some PCS devices (1710–1810 MHz, 1750–1870 MHz and 1850–1990 MHz), cordless telephones (902–928 MHz) or Blue Tooth Specification 2.4–2.5 GHS frequency ranges.

The antenna system **10** of FIGS. **1**, **2**A and **3** includes a dielectric substrate **12** with cover layers **14**, **16**. Printed on the substrate **12** is a first conductive layer **20**, which is a micro-strip line, and on the opposite side is a split dipole conductive layer **30**. The first conductive layer **20** is generally L-shaped having legs **22**, **24**. The second conductive layer **30** includes a generally U-shaped strip balloon line portion **32** having a bight **31** and a pair of separated legs **33**. Extending transverse and adjacent the ends of the legs **33** are a plurality of strips **35**, **37**, **34**, **36**. Leg **22** of the first conductive layer **20** is superimposed upon one of the legs **33** of the second conductive layer **30** with the other leg **24** extending transverse a pair of legs **33**. A conductive via **40** connects the end of leg **24** to one of the legs **33** through the

dielectric substrate **12**. Terminal **26** at the other end of leg **22** of the first conductive layer **20** receives the drive for the antenna **10**.

The four strips **34**, **36**, **35** and **37** are each uniquely dimensioned so as to be tuned to or receive different frequency signals. They are each dimensioned such that the strip has a width less than 0.05 λ0 and a total length of less than 0.5 λ0.

FIG. **2**B shows a modification of FIG. **2**A, including six strips **35**, **37**, **39**, **34**, **36**, **38** each extending from an adjacent end of the legs **33** of the second conductive layer **30**. This allows tuning and reception to six different frequency bands. The strips of both embodiments are generally parallel to each other.

The dielectric substrate **12** may be a printed circuit board, a fiberglass or a flexible film substrate made of polyimide. Covers **14**, **16** may be additional, applied dielectric layers or may be hollow casing structures. Preferably, the conductive layers **20**, **30** are printed on the dielectric substrate **12**.

As an example of the quad-band dipole antenna of FIG. **1**, the frequencies may be in the range of, for example, 2.4–2.487, 5.15–5.25, 2.25–5.35 and 5.74–5.825 GHz. For the directional diagram of FIG. **4**, the directional gain is illustrated in FIG. **5** for two of the frequencies 2.4 GHz (Graph A) and 5.6 GHz (Graph B). A maximal gain at 90 degrees is 5.45 dB at 2.4 GHz and 6.19 dB at 5.6 GHz. VSWR and the magnitude **S11** are illustrated in FIG. **6**. VSWR is below 2 at the 2.4 GHz and the 5.6 GHz frequency bands. The bands from 5.15–5.827 merge at the 5.6 GHz frequency.

The height h of the dielectric substrate **12** will vary depending upon the permeability or dielectric constant of the layer.

The narrow, rectangular strips **34**, **36**, **35**, **37** of the appropriate dimension increases the total gain by reducing the surface waves and loss in the conductive layer. The number of conductive strips also effects the frequency sub-band.

The position of the via **40** and the slot S between the legs **33** of the U-shaped sub-conductor **32** effect the antenna performance related to the gain "distributions" in the frequency bands. A width of slot dimensions S and the location of the via **40** are selected so as to have approximately the same gain in all of the frequency bands of the strips **34**, **36**, **35**, **37**. The maximum theoretical gain obtained are above 4 dB and are 5.7 dB at 2.4 GHz and 7.5 dB at 5.4 GHz.

FIG. **7**A is a graph for the various positions of the feed point fp or via **40** and the effect on VSWR and **S11**. The center feed point fp**1** corresponds to the results of FIG. **6**. Although the change of the feed point fp has a small effect in gain, it has a greater effect in shifting the λ0 at the second frequency band in the 5 GHz range.

FIG. **8** shows the effect of changing the slot width from 1 mm to 3 mm to 5 mm. The 3 mm slot width corresponds to FIG. **6**. Although there is not much change in the VSWR, there is substantial change in the gain at **S11**. For example, for the 5 mm strip, **S11** is −21 dB at 2.5 GHz and −16 dB at 5.3 GHz. For the 3.3 mm strip, **S11** is −14 dB at 2.5 GHz and −25 dB at 5.23 GHz. For the 1 mm strip, **S11** is approximately equal to −13 dB at 2.5 GHz and at 5.3 GHz.

It should be noted that changing the length of legs **34**, **35**, **36**, **37** between 5 mm, 10 nm and 15 mm has very little effect on VSWR and the gain at **S11**. FIG. **6** corresponds to a 15 mm length. Also, changing the distance between the legs **34**, **35**, **36**, **37** to between 1 mm, 2 mm and 4 mm also has very little effect on VSWR and the gain at **S11**. Two millimeters of separation is reflected in FIG. **6**. The difference in gain between the 2 mm and the 4 mm spacing was approximately 2 dB. FIG. **9** shows the response of 2, 3 and 4 dipole strips.

FIGS. **10**A and **10**B show the effect of changing the width of the dipole while maintaining the width of the individual strips. The width of the dipole varies from 6 mm, 8 mm to 10 mm. The 6 mm width corresponds to that of FIG. **6**. For the 6 mm width, there are two distinct frequency bands at 2.4 having an **S11** gain of −14 dB and at 5.3 GHz having an **S11** gain of −25 dB. For the 8 mm width, there is one large band having a VSWR below two extending from 1.74 to 5.4 GHz and having an **S11** gain of approximately 20 dB. Similarly, the 10 mm width is one large band at a VSWR below two extending from 1.65 to 5.16 GHz and having a gain at 2.2 GHz of −34 dB to a gain at 4.9 GHz of −11 dB.

A directional or unidirectional dipole antenna incorporating the principles of the present invention is illustrated in FIGS. **7** through **9**. Those elements having the same structure, function and purpose as that of the omni-directional antenna of FIG. **1** have the same numbers.

The antenna **11** of FIGS. **11** through **13** includes, in addition to the first conductive layer **20** on a first surface of the dielectric substrate **12** and a second conductive dipole **30** on the opposite surface of the dielectric substrate **12**, a ground conductive layer **60** separated from the second conductive layer **30** by the lower dielectric layer **16**. Also, a third conductive element **50** is provided on the same surface of the dielectric substrate **12** as the first conductive element **20**. The third conductive element **50** is a directive dipole. It includes a center strip **51** having a pair of end portions **53**. This is generally a barbell-shaped conductive element. It is superimposed over the strips **34**, **36**, **35**, **37** of the second conductive layer **30**. It is connected to the ground layer **60** by a via **42** extending through the dielectric substrate **12** and dielectric layer **16**.

The directive dipole **50** includes a plurality of fingers superimposed on a portion of the edges of each of the strips **34**, **36**, **35**, **37**. As illustrated, the end strips **52**, **58** are superimposed and extend laterally beyond the lateral edges of strips **34**, **36**, **35**, **37**. The inner fingers **54**, **56** are adjacent to the inner edge of strips **34**, **36**, **35**, **37** and do not extend laterally therebeyond.

Preferably, the permeability or dielectric constant of the dielectric substrate **12** is greater than the permeability or dielectric constant of the dielectric layer **16**. Also, the thickness h**1** of the dielectric substrate **12** is substantially less than the thickness h**2** of the dielectric layer **16**. Preferably, the dielectric substrate **12** is at least half of the thickness of the dielectric layer **16**.

The polygonal perimeter of the end portion **53** of the dipole directive **50** has a similar shape of the PEAN03 fractal shape directive dipole. It should also be noted that the profile of the antenna **12** gives the appearance of a double planar inverted-F antenna (PIFA).

FIG. **14** is a graph of the directional gain of antenna **12**, while FIG. **15** shows a graph for the VSWR and the gain **S11**. Five frequencies are illustrated in FIG. **10**. The maximum gain are above 7 dB and are 8.29 dB at 2.5 GHz and 10.5 dB at 5.7 GHz. The VSWR in FIG. **15** is for at least two frequency bands that are below 2.

FIGS. **16**A and **16**B show the effect of the feed point fp or via **40**. Feed point zero is similar to that shown in FIG. **15**. FIG. **17** shows the effect of the slot width S for 1 mm, 3 mm and 5 mm. The 3 mm width corresponds generally to that of FIG. **15**. FIGS. **18**A and **18**B show the effect of the dipole strip width SW for widths of 6 mm, 8 mm and 10 mm. The 6 mm width corresponds to that of FIG. **15**. FIGS. **19**A and **19**B show the effect of the length SDL of portion **51** of the

directive dipole **50** on the second frequency in the 5 GHz range. The 8 mm width corresponds generally to that of FIG. **15**.

Although not shown, a number of via holes around the dipole through the insulated layer **12** may be provided. These via holes would provide pseudo-photonic crystals. This would increase the total gain by reducing the surface waves and the radiation in the dielectric material. This is true of both antennas.

Although the present disclosure has been described and illustrated in detail, it is to be clearly understood that this is done by way of illustration and example only and is not to be taken by way of limitation. The scope of the present disclosure is to be limited only by the terms of the appended claims.

What is claimed:

**1**. A dipole antenna for a wireless communication device comprising:

a first conductive element superimposed a portion of and separated from a second conductive element by a first dielectric layer;

the second conductive element being generally U-shaped;

the second conductive element including a plurality of spaced conductive strips extending an equal length transverse from adjacent ends of each leg of the U-shape; and

a first conductive via connects the first and second conductive elements through the first dielectric layer such that each strip on a leg being dimensioned for a different λo relative to the first conductive via.

**2**. The antenna according to claim **1**, wherein the first and second conductive elements are each planar.

**3**. The antenna according to claim **1**, wherein each strip has a width less than 0.05 λo and a length of less than 0.5 λo.

**4**. The antenna according to claim **1**, wherein the antenna is omni-directional and a gain exceeding 4 dB.

**5**. The antenna according to claim **1**, wherein the first dielectric layer is a substrate, and the first and second conductive elements are printed elements on the substrate.

**6**. The antenna according to claim **1**, wherein the plurality of strips are parallel to each other.

**7**. The antenna according to claim **1**, wherein the first conductive element is L-shaped.

**8**. The antenna according to claim **7**, wherein one of the legs of the L-shape is superimposed one of the legs of the U-shape.

**9**. The antenna according to claim **8**, wherein the first conductive via connects the other leg of the L-shape to the other leg of the U-shape.

**10**. The antenna according to claim **7**, wherein the first conductive via connects an end of one of the legs of the L-shape to one of the legs of the U-shape.

**11**. The antenna according to claim **7**, wherein one of leg of the L-shape is superimposed on one leg of the U-shape and a portion of another leg of the L-shape is superimposed on another leg of the U-shape.

**12**. A dipole antenna for a wireless communication device comprising:

a first conductive element superimposed a portion of and separated from a second conductive element by a first dielectric layer;

a first conductive via connects the first and second conductive elements through the first dielectric layer;

the first conductive element being L-shaped;

the second conductive element being generally U-shaped;

the second conductor including a plurality of spaced conductive strips extending transverse from adjacent ends of each leg of the U-shape;

each strip on a leg being dimensioned for a different λo;

a ground plane conductor superimposed and separated from the second conductive element by a second dielectric layer;

a third conductive element superimposed and separated from the strips of the second conductive element by the first dielectric layer; and

a second conductive via connecting the third conductive element to the ground conductor through the dielectric layers.

**13**. The antenna according to claim **12**, wherein the first and third conductive elements are co-planar.

**14**. The antenna according to claim **12**, wherein the third conductive element includes a plurality of fingers superimposed a portion of lateral edges of each of the strips.

**15**. The antenna according to claim **12**, wherein a first and last finger superimposed a first and last strip on each leg of the U-shape extend laterally beyond the lateral edges of the respective strips.

**16**. The antenna according to claim **12**, wherein the permeability of the first dielectric layer is substantially greater than the permeability of the second dielectric layer.

**17**. The antenna according to claim **16**, wherein the thickness of the first dielectric layer is substantially less than the thickness of the second dielectric layer.

**18**. The antenna according to claim **12**, wherein the thickness of the first dielectric layer is at least half the thickness of the second dielectric layer.

**19**. The antenna according to claim **12**, wherein the antenna is directional and has a gain exceeding 7 dB.

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**Before the**
**Federal Communications Commission**
**Washington, D.C. 20554**

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| In the Matter of | ) |
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| Implementation of Section 6002(b) of the Omnibus Budget Reconciliation Act of 1993 | ) |
| | ) |
| Annual Report and Analysis of Competitive Market Conditions With Respect to Commercial Mobile Services | ) |
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# SIXTH REPORT

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By the Commission:

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commerce, which will likely play a more prominent role in the mobile data industry as it evolves.[31] Many analysts expect that the development and deployment of advanced wireless or Third Generation ("3G") services[32] will increase the growth of mobile data services over the next several years. During 2000 and early 2001, several U.S. mobile telephone carriers announced their 3G rollout plans. At least six carriers expect to begin deploying network technologies during late 2001 and early 2002 that will allow for mobile Internet access speeds of up to 144 kbps.[33]

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31 *See* Section II.B.3, Developing Mobile Data Services, *infra*.

32 3G generally refers to high-speed advanced mobile services and the technologies that will make such services available. 3G speeds are expected to reach 2 Mbps from a fixed location, 384 kbps at pedestrian speeds, and 144 kbps at traveling speeds of 100 kilometers per hour. *See Fifth Report*, at 17695. "2.5G" refers to the interim technologies that carriers will use while migrating from their current 2G technologies of CDMA, TDMA, GSM, and iDEN to 3G technologies. Some members of the wireless industry label certain technologies as "3G," while others label the same technology as "2.5G." Therefore, it is difficult to place the next generation of network technologies into catergories, but the 2.5G and 3G technologies include General Packet Radio Service ("GPRS"), Enhanced Data rates for GSM Evolution ("EDGE"), Wideband CDMA ("WCDMA"), cdma2000 1X, cdma2000 1XEV, and cdma2000 3XRTT. WCDMA is also known as UMTS (Universal Mobile Telecommunications System). The general migration path for GSM and TDMA carriers is to implement GPRS, then possibly EDGE and eventually WCDMA, while the current CDMA carriers will likely deploy the cdma2000 technologies. *See* Section II.B.1.c, 3G Developments, *infra*.

33 *See* Section II.B.1.c, 3G Developments, *infra*. These carriers include the six nationwide mobile telephone carriers discussed in Section II.A.1.a(iii), Building Nationwide Networks, *infra*.